ANNUAL PROJECT SUMMARY

AWARD NUMBER: 04HQAG0109

OPERATION OF THE JOINT EARTHQUAKE NOTIFICATION SYSTEM IN NORTHERN CALIFORNIA:
Collaboration between UC Berkeley
and the USGS, Menlo Park

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KEY WORDS: Seismology; Real-time earthquake information

1. INVESTIGATIONS UNDERTAKEN

In northern California, the BSL and the USGS Menlo Park collaborate to provide the timely and reliable earthquake information to the federal, state, and local governments, to public and private agencies, and to the general public. This joint earthquake notification system provides enhanced earthquake monitoring by building on the strengths of the Northern California Seismic Network, operated by the USGS Menlo Park, and the Berkeley Digital Seismic Network (BDSN), operated by the UC Berkeley Seismological Laboratory.

During this reporting period, the BSL worked with the USGS Menlo Park to enhance and improve earthquake reporting in northern California. Important areas of activity include:

- Parkfield earthquake
- Design and preliminary implementation of new software system

1.1 Current Capabilities

In 1996, the BSL and USGS began collaboration on a joint notification system for northern and central California earthquakes. The current system merges the programs in Menlo Park and Berkeley into a single earthquake notification system, combining data from the NCSN and the BDSN. Today, the BSL and USGS system forms the Northern California Management Center (NCMC) of the California Integrated Seismic Network (CISN), which is the California ”region” of the ANSS.

The details of the Northern California processing system and the REDI project have been described in past annual reports. In this section, we will describe how the Northern California Management Center fits within the CISN system, detail recent developments, and discuss plans for the future development.

Figure 1 illustrates the NCMC as part of the the CISN communications ring. The NCMC is a distributed center, with elements in Berkeley and Menlo Park. The 35 mile separation between these two centers is in sharp contrast to the Southern California Management Center, where the USGS Pasadena is located across the street from the Caltech Seismological Laboratory. With funding from the State of California, the CISN partners have established a dedicated T1 communications link, with the capability of falling back to the Internet. In addition to the CISN ring, the BSL and the USGS Menlo Park have a second dedicated communication link to provide bandwidth for shipping waveform data and other information between their processing systems.

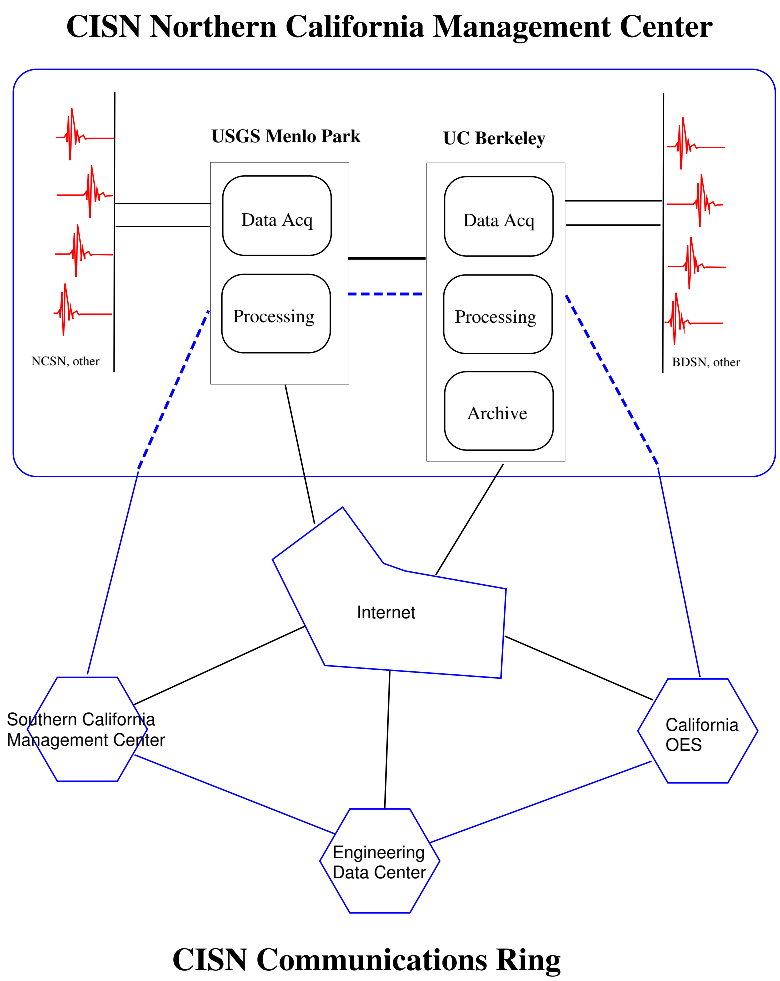

Figure 1: Schematic diagram illustrating the connectivity between the real-time processing systems at the USGS Menlo Park and UC Berkeley, forming the northern California Management Center, and with other elements of the CISN.

Figure 2 provides more detail on the current system at the NCMC. At present, two Earthworm-Earlybird systems in Menlo Park feed two "standard" REDI processing systems at UC Berkeley. One of these systems is the production or paging system; the other is set up as a hot backup. The second system is frequently used to test new software developments before migrating them to the production environment. The Earthworm-Earlybird-REDI systems perform the standard detection, location, estimation of M_d, M_L, and M_w, as well as processing of ground motion data. The computation of ShakeMaps is also performed on two systems, one in Menlo Park and one in Berkeley, as described below. An additional system performs finite-fault processing and the computation of higher level ShakeMaps (ShakeMaps that account for finite faulting).

The dense network and Earthworm-Earlybird processing environment of the NCSN provides rapid and accurate earthquake locations, low magnitude detection thresholds, and first-motion mechanisms for smaller quakes. The high dynamic range data loggers, digital telemetry, and broadband and strong-motion sensors of the combined BDSN/NCSN and REDI analysis software provide reliable magnitude determination, moment tensor estimation, peak ground motions, and source rupture characteristics. Robust preliminary hypocenters are available about 25 seconds after the origin time, while preliminary coda magnitudes follow within 2-4 minutes. Estimates of local

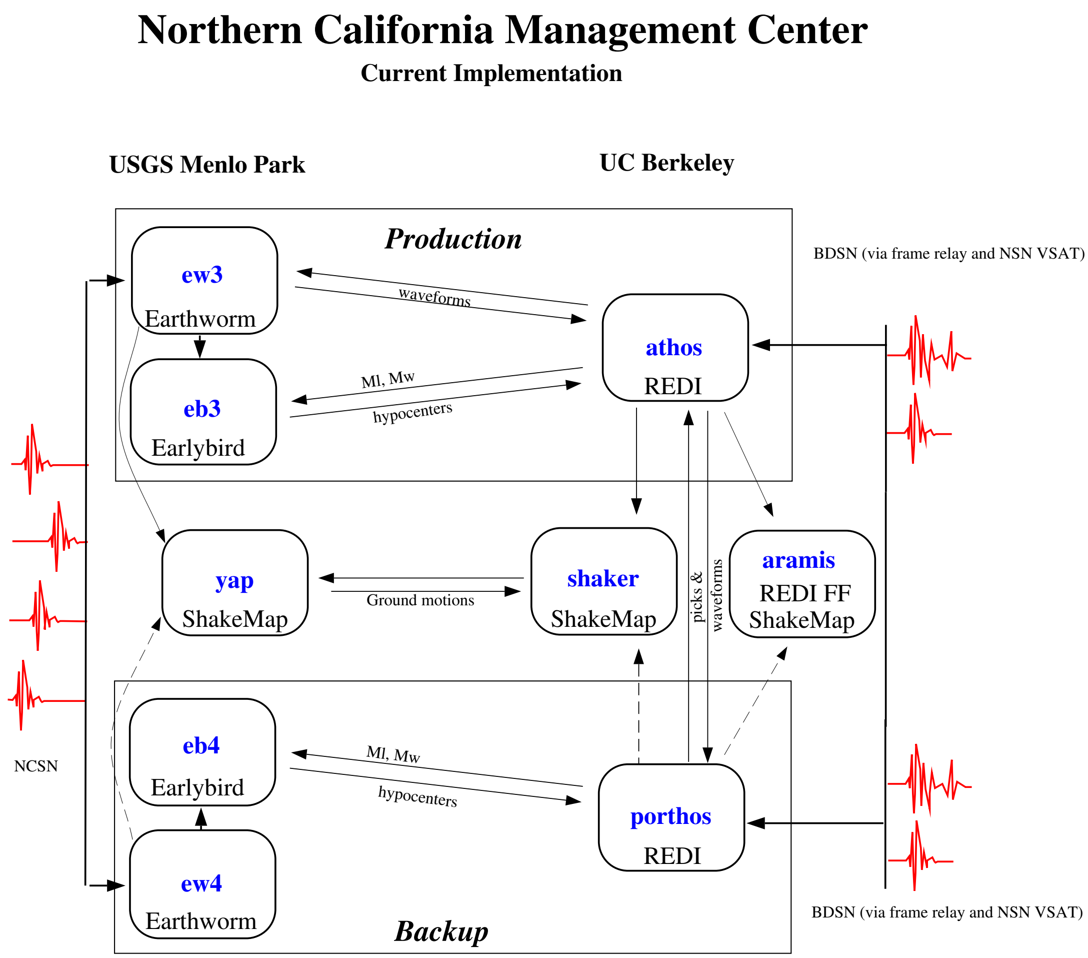

Figure 2: Detailed view of the current Northern California processing system, showing the two Earthworm-Earlybird-REDI systems, the two ShakeMap systems, and the finite-fault system.

magnitude are generally available 30-120 seconds later, and other parameters, such as the peak ground acceleration and moment magnitude, follow within 1-4 minutes (Figure 3).

Earthquake information from the joint notification system is distributed by pager/cellphone, e-mail, and the WWW. The first two mechanisms ”push” the information to recipients, while the current Web interface requires interested parties to actively seek the information. Consequently, paging and, to a lesser extent, e-mail are the preferred methods for emergency response notification. The *recenteqs* site has enjoyed enormous popularity since its introduction and provides a valuable resource for information whose bandwidth exceeds the limits of wireless systems and for access to information which is useful not only in the seconds immediately after an earthquake, but in the following hours and days as well.

2. RESULTS

2.1 Earthquake Monitoring

From 5/1/2004 (the initiation of this contract) to 12/31/2004, over 11,000 earthquakes have been processed by the joint notification system in northern California. Most of these events were small

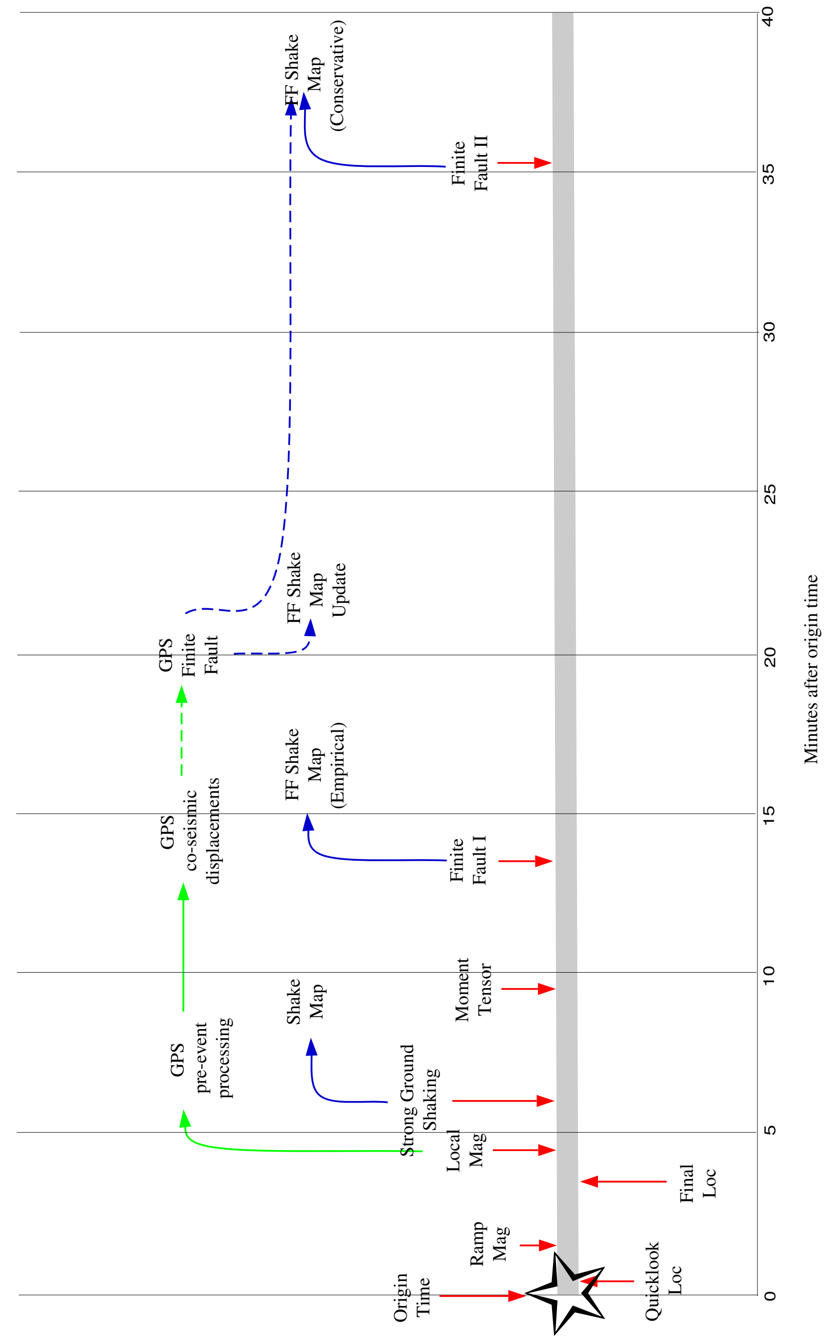

Figure 3: Illustration of the current (solid lines) and planned/proposed (dotted lines) development of real-time processing in northern California. The Finite Fault I and II are fully implemented within the REDI system at UC Berkeley and are integrated with ShakeMap. The resulting maps are still being evaluated and are not currently available to the public.

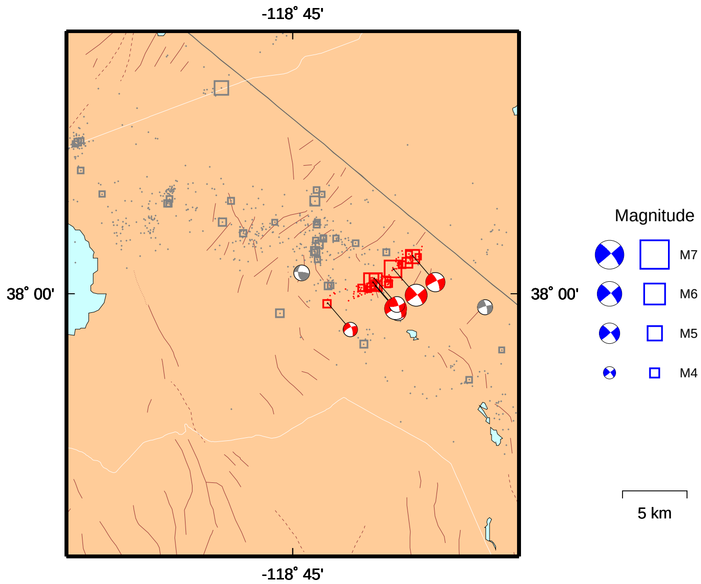

Figure 4: Map showing the earthquake sequence east of Mono Lake (red) with automatic moment tensor solutions and background seismicity (grey).

earthquakes, although a small number represent mislocated teleseisms, microwave glitches, or other blown events. This is an unusually large number of events for a 7-month time period, owing to the December 2003 San Simeon and September 2004 Parkfield earthquakes.

Of the total, 326 events had an M_d greater than 3.0, 82 events had an M_L greater than 3.5, and 9 earthquakes with M_L greater than 5 were recorded.

2.1.1 Special Events

The big earthquake story during the time period of this report is the September 28, 2004 Parkfield earthquake. Actually, September was an active month overall, with a sequence of M5 events east of Mono Lake in addition to the Parkfield earthquake.

On September 18, an earthquake sequence initiated near the California/Nevada border, just east of Mono Lake and beneath the Adobe Hills. This series of events started on 9/18 at 12:02 local time with an M2.3 earthquake. It was followed by an M4.1 (12:08 AM), the 5.5 at (04:02 PM), a 5.4 (04:43 PM), and a 4.1 (04:47 PM) as well as numerous events less than M4. The sequence continued through September and October (M4.7) and was still active as 2004 drew to a close (at the M1.5-2.5 level). Figure 4 shows the sequence as of late September and was part of a Web page put together by the BSL and the USGS as part of the CISN Northern California Management Center: `http://www.cisn.org/special/evt.04.19.18/`.

While Lind Gee and David Oppenheimer were attending a meeting of the ANSS TIC/NIC and the National Earthquake Conference in St. Louis, MO, the Parkfield earthquake occurred. This event was the second M6+ event to strike Northern California within 9 months. Interestingly, many aspects of the response were better coordinated than previous earthquakes, since Berkeley, Menlo Park, Pasadena, Golden, and Reston personnel were all in the same room.

Overall, the timing and performance of the automatic systems during Parkfield were similar to

CISN Timing		
Earthquake Information	UTC Time	Elasped time (HH:MM:SS)
Origin Time (OT)	09/28 17:15:24	00:00:00
Quick Look hypocenter	09/28 17:15:55	00:00:31
Final hypocenter & M_d	09/28 17:19:57	00:04:33
First Motion mechanism	09/28 17:20:10	00:04:46
Local Magnitude	09/28 17:20:30	00:05:06
1st ShakeMap completed (M_L 6.0)	09/28 17:21:16	00:05:52
Moment Tensor mechanism & M_w	09/28 17:22:19	00:06:55
2nd ShakeMap completed	09/28 17:28:08	00:07:44
Analyst review of location	09/28 17:46:–	00:31:–
Analyst review of moment tensor	09/28 17:47:–	00:32:–
ShakeMap update with relocated hypocenter	09/28 17:53:–	00:38:–
Analyst review of line source	09/28 17:54:–	00:39:–
Aftershock probability statement released	09/28 18:00:–	00:45:–
ShakeMap update with line source	09/28 18:20:–	01:05:–
Updated aftershock statement	09/28 18:23:–	01:08:–
ShakeMap update with 6 stations	09/28 21:18:–	04:03:–
Earthquake Report at cisn.org	09/28 21:45:–	04:30:–
1st Internet Quick Report at cisn-edc.org	09/29 01:56:–	08:41:–
ShakeMap update with 1 additional station	09/29 05:20:–	12:05:–
ShakeMap update with analog data	10/08 –:–:–	10 days

Table 1: Timing of earthquake information for the Parkfield earthquake.

that observed during San Simeon [*Gee et al.*, 2004]. There were problems with the automatic location of the mainshock, owing to the weighting of distant observations, which were quickly identified (since the epicenters were located a few kilometers west of the fault trace) and manually corrected. It is possible that this problem with distance weighting also occurred during the San Simeon sequence, but was not recognized. There was also some problems with automatic magnitudes. Estimates of M_d and M_L for several of the aftershocks were contaiminated by the wave train of the mainshock and were biased high. This problem is difficult to solve, although the test system running the new magnitude estimation program (based on the TriNet software) did slightly better (for example, 4.6 instead of 5.0 - actual magnitude is 4.1-4.2).

Although the NCMC locates thousands of earthquakes annually, M6+ events are different from the routine processing associated with the more common, smaller earthquakes. Because larger events have extended source regions and are relatively infrequent, they can exercise software in unexpected ways and overwhelm humans unaccustomed to response procedures. Moreover, they rarely happened when convenient!

As indicated by Table 1, most of the routine automatic processing performed well the Parkfield earthquakes. The occurrence of the San Simeon earthquake, several months earlier, illuminated several software bugs. These had fixed by the time of Parkfield. However, the Parkfield earthquake exercised different aspects of the system - for example, the procedures for updating magnitudes after a reviewed moment tensor solution - and problems in this code were discovered.

One of the main lessons of the Parkfield earthquake is the importance of frequent drills. In both Berkeley and Menlo Park, the human response was less than it should have been. One of the significant benefits we anticipate from the effort to develop joint system software is that both Berkeley and Menlo Park will be running the SAME software. And this software will be largely the SAME as in southern California. This will provide very strong economies of scale both in terms of software development as well as trained responders.

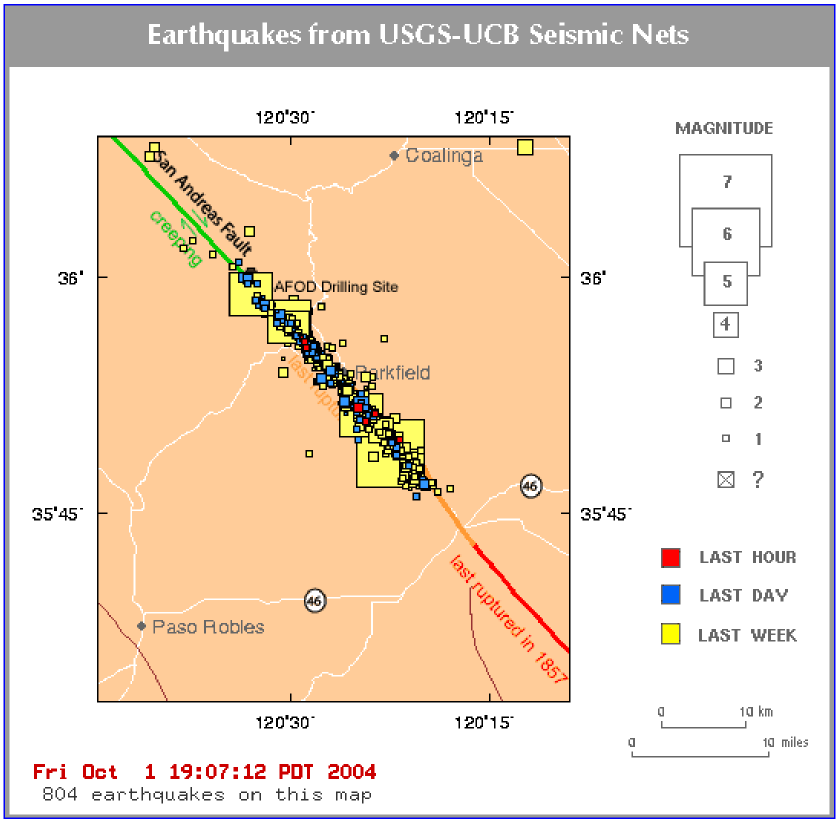

Figure 5: Figure from the *recenteqs* Web page following the Parkfield earthquake.

2.2 New system development

2.2.1 Overview

In the past few months, Berkeley and Menlo Park staff have continued to work on the development of a new system. As indicated in previous reports, the design draws on the developments in the TriNet system. In this section, we briefly report on several aspects of this effort.

2.2.2 Magnitude

We have made progress on implementing codes for determination of M_L and M_e. As described in the final report for Grant 01HQAG0020, the BSL and the USGS Menlo Park have implement the `rad` code for computing reduced amplitude timeseries. BSL staff designed a series of programs to allow these reduced amplitudes to be exchanged via an Earthworm `import/export`. These codes were implemented in the spring of 2004 and the NCMC now has reduced amplitude timeseries for all digital stations in the network. Figure 6 compares the amplitudes from this system with amplitudes computed in the current system. Overall, the comparison is very encouraging, although there is a slight bias where the time domain amplitudes are smaller than the frequency domain amplitudes. We believe that the bias can be explained by the difference between simply removing the gain (as is done in the time-domain) versus the full instrument response (as is done in the frequency domain).

The BSL has been running the magnitude software for several months on a test system. Overall, it is doing well for events of M3 and higher, but below M3, issues associated with the sparseness of the network show up.

2.2.3 Wave Server

Another area where we have made progress in the last few months is the implementation of a Proxy Wave Server (PWS) for use within the NCMC. The PWS implements the same application programming interface (API) used by the various components of the SCSN/SCEDC data processing and archiving software, but can interact with and retrieve data from the various different waveservers in use within the NCMC. This will allow the NCMC to utilize SCSN/TriNet software developed for retrieving and archiving waveform data with the NCMC waveservers.

The next step for the NCMC is to implement the rules for determining the time windows and channel list fo use for archiving timeseries for detected events and subnet triggers from the real-time system.

2.2.4 Jiggle

In order to help migrate the Berkeley and Menlo Park into a single post-processing system, the NCMC plans to implement `Jiggle` in Northern California. Over the past couple of years, effort in Southern California added a M_d module to the application.

The BSL is currently configuring the newest version of the `Jiggle` sofware that can compute coda magnitudes for testing in northern California. We have populated the database with the initial coda magnitude parameters, and need to benchmark the Jiggle-produced magnitudes with those computed by the existing CUSP system.

Once tested - and when combined with rules for retrieving waveform data abve - this will allow USGS and BSL timers to begin testing `Jiggle` in parallel with the current systems.

2.2.5 Other Major issues

As we move forward with this development, a number of significant issues need to be addressed. In October, 2004, Berkeley and Menlo Park staff visited Pasadena to discuss software development with Caltech and USGS Pasadena staff.

Areas of discussion included:

- How to accomodate M_d
- How to incorporate quick hypocenters
- How to handle delayed or late data (such as significant telemetry outages)
- How to handle external events (such as the LBL Geysers system)
- How to handle ”quick review” using lightweight tools other than Jiggle

These are all significant issues for Northern California, due to the non-uniform nature of the networks. In Southern California, the network is more uniform and some of these issues have never been raised.

Some progress was made in the October meeting, but there is still significant effort to be undertaken. More details about the effort are described here: `http://www.cisn.org/ncmc/`.

2.3 References

Gee, L., D. Oppenheimer, T. Shakal, D. Given, and E. Hauksson, Performance of the CISN during the 2003 San Simeon Earthquake, `http://www.cisn.org/docs/CISN_SanSimeon.pdf`, 2004.

Gee, L., D. Neuhauser, D. Dreger, M. Pasyanos, R. Uhrhammer, and B. Romanowicz, The Rapid Earthquake Data Integration Project, *Handbook of Earthquake and Engineering Seismology*, IASPEI, 1261-1273, 2003.

Gee, L., D. Neuhauser, D. Dreger, M. Pasyanos, B. Romanowicz, and R. Uhrhammer, The Rapid Earthquake Data Integration System, *Bull. Seis. Soc. Am., 86*, 936-945,1996.

3. NON-TECHNICAL ABSTRACT

This project focuses on the development and implementation of hardware and software for the rapid assessment of earthquakes. The Berkeley Seismological Laboratory collaborates with the USGS Menlo Park to monitor earthquakes in northern California and to provide rapid notification to public and private agencies for rapid response and assessment of earthquake damage.

During this time period, we continued to work on the design and development of software to improve the Northern California Seismic System. The 2004 Parkfield earthquake

began the design and development of software to improve the Northern California Seismic System.

4. REPORTS PUBLISHED

Gee, L., D. Oppenheimer, T. Shakal, D. Given, and E. Hauksson, Performance of the CISN during the 2003 San Simeon Earthquake, `http://www.cisn.org/docs/CISN_SanSimeon.pdf`, 2004.

5. MEETING PRESENTATIONS

Dreger, D., Lombard, O., Boatwright, J., Wald D., and L. Gee, Finite source models of the December 22, 2003 San Simeon earthquake and applications to ShakeMap (abstract), *Seismol. Res. Lett., 75*, 293, 2004.

Gee, L., J. Polet, R. Uhrhammer, and K. Hutton, Earthquake Magnitudes in California, *Seism. Res. Lett., 75(2)*, 272, 2004b.

6. DATA AVAILABILITY

Data and results from the REDI project are available at the Northern California Earthquake Data Center (*//www.quake.geo.berkeley.edu*) For additional information on the REDI project, contact Lind Gee at 510-643-9449 or lind@seismo.berkeley.edu.

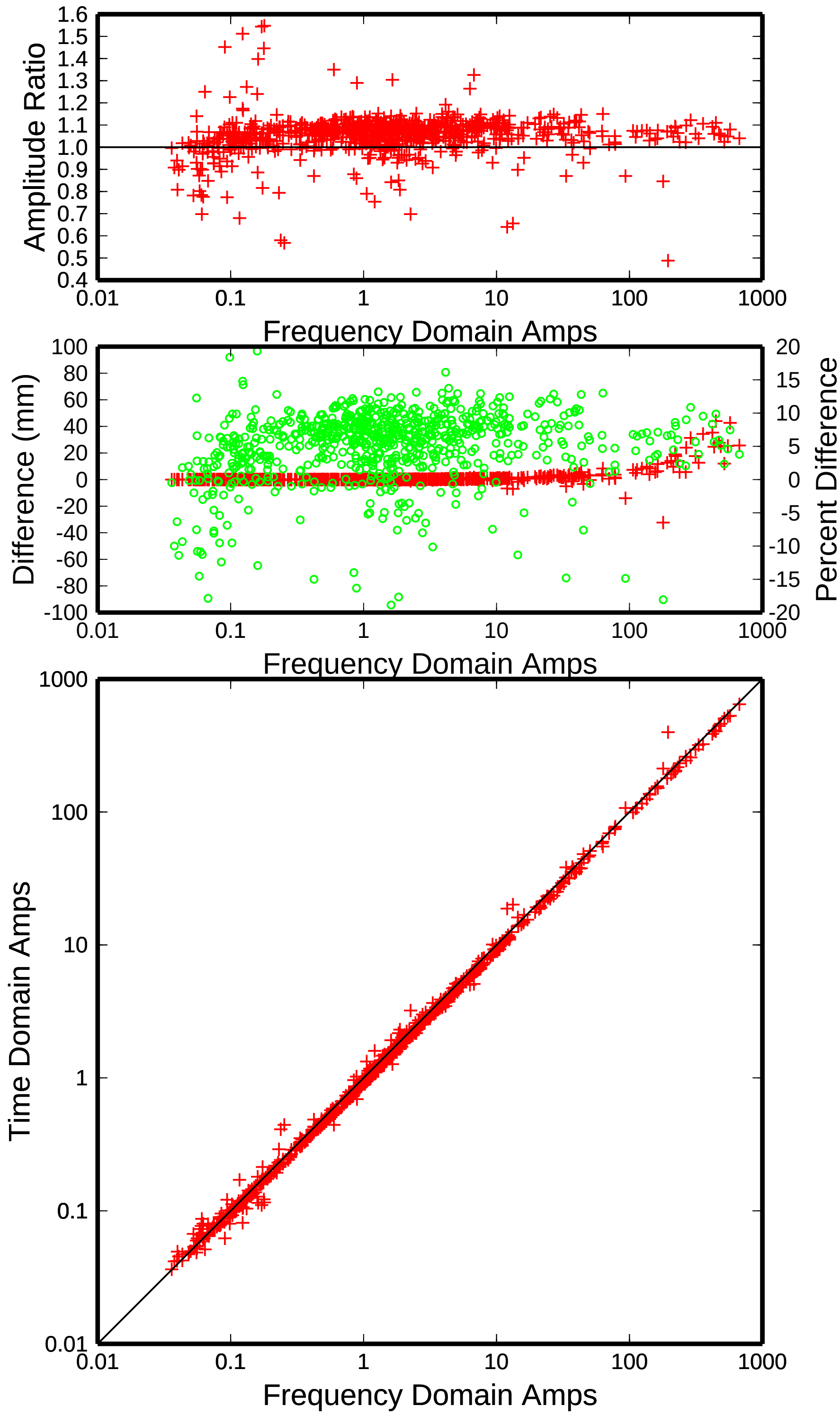

Figure 6: Figure comparing amplitude estimates in the time domain (TD) (made from the TriNet software) with those made in the frequency domain (FD) (made from the current NCMC system). Bottom: Comparison of frequency versus time domain amplitudes for a number of earthquakes. Overall, this plot shows a linear relationship with a few outliers. However, FD amps are consistently larger than the TD amps. Middle: Difference in the amplitudes (red crosses are the difference in mm; green circles are the percentage difference). Note that the magnitude of the difference increases with larger amplitudes, although the percentage remains roughly similar. Extreme outliers are off the scale. Top: Amplitude ratio. A small but consistent bias around

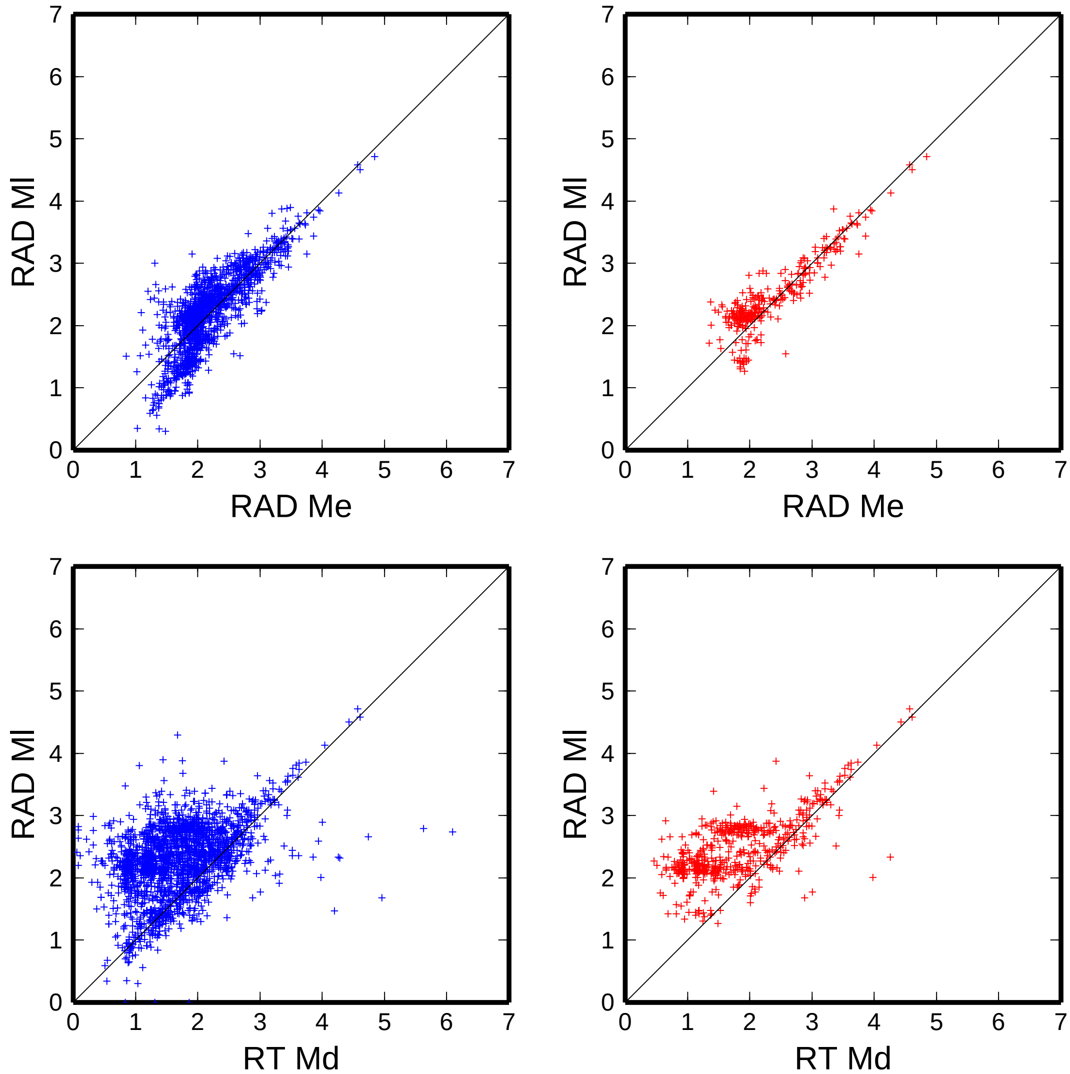

Figure 7: Figure comparig magnitudes estimate from timedomain and frequency domain amplitudes. The leftmost panels are magnitude comparisons for all events - M_L versus M_d and M_L versus M_e . The right panels (red) show the same data with the restriction that at least 10 channels be used. This application of a quality criteria cleans up the magnitudes somewhat and what becomes evident is the the network noise floor below M_d 3.

Annual Non-Technical Summary

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